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A joint mind consideration of the Drake equation in the search for extraterrestrial intelligence

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ABSTRACT

Numerous estimates exist of the factors appearing in the Drake equation, which estimates the number of extant communicative civilizations in the Milky Way galaxy. Although each are presented by scholars in the field, wide disagreement of the values of those factors exist. Here we consider the six non-longevity factors as random variables and utilize estimates from six studies to determine probability density functions for those factors. We then utilize them to perform a Monte Carlo analysis to determine the most likely value for the product. We find, in moderately close agreement with the estimate by both Frank Drake and the Cyclops report, a value for the product of 0.85 ± 1.28 years^{-1}.

1. Introduction

1.1. Summary of the paper

The Drake equation estimates the number of extant communicative civilizations in the Milky Way galaxy. It does so by considering the values of six astronomical, biological, and engineering factors and a seventh factor, the longevity of the communicative civilization. We consider the six non-longevity factors as random variables and, using widely varying estimates of their values from six studies, we determine the parameters of their probability density functions. We then use a Monte Carlo analysis to determine 5000 values for each factor and multiply them together to determine a distribution of the 5000 products. We find, in moderately close agreement with the estimate by both Frank Drake and the Cyclops report, a value for the product of 0.85 ± 1.28 years^{-1}. This approach incorporates the uncertainties in the estimates of each of the investigators and contributors and thereby represents the expertise of their combined minds, the figurative creation of a joint mind.

1.2. Frank Drake and the Drake equation

The genius of astronomer Frank Drake (b. 1930) was to take the complete unknown of the number of extant communicative extraterrestrial civilizations and break it up into a sequence of factors, each of which can be estimated. As in order of magnitudes calculations, some of the estimates may be low and some may be high, but if no bias exists the various errors will cancel, yielding an estimate in which one can have confidence.

The result was the Drake equation. Drake devised it in 1961 to create an organizing agenda for a conference he had organized to discuss the possibility of contact with extraterrestrial civilizations at Green Bank, West Virginia, the site of the National Radio Astronomy Observatory. Using its 85-foot diameter radio telescope, he had just completed Project Ozma, the first attempt to detect such signals, generating worldwide interest.

The Drake equation is

$$N = R_* f_p n_e f_l f_i f_c L, \tag{1}$$

where N is the number of technical, communicative civilizations existing at any time, R_* is the rate of star formation currently and in the recent astrophysical past, f_p is the fraction of those stars which have planetary systems, n_e is the number of planets around the star within its habitable or ecological region, f_l is the fraction of those habitable planets on which life evolves, f_i is the fraction of those planets on which the life develops intelligence, f_c is the fraction of those planets on which the intelligent life develops the technology for interstellar communication, and L is the longevity of the communicative civilizations. The Drake equation provides the factors in the order of that in which we have the most confidence to that in which we have the least confidence.

The Drake equation is discussed in detail in a number of books on the

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FEEDBACK

possibility of extraterrestrial life and to a lesser extent in astronomy textbooks. Estimates for the various factors differ according to the investigator.

1.3. Previous work

Maccone [1] performed an analysis imposing uniform distributions on all the factors of the Drake equation, including one related to the longevity, in which means and standard deviations were determined and employed to generate individual distributions resulting in a distribution of N. We find numerous aspects of this study lacking justification. First, the expression presented by Maccone is related to but is not the Drake equation. The Drake equation is an estimate of the number of extant communicative civilizations and is achieved by multiplying a rate by a time scale. Its beauty lies in the successive factors being increasingly unknown, from a moderately well-known estimate of the current and recent epoch rate of star formation to the completely unknown factor of the longevity of communicative civilizations, L. To place the latter on the same footing as the former provides an injustice to the philosophy behind the Drake equation. Second, numerous studies have discussed the values for the various factors. Maccone ignores these studies and imposes his own as mean values without justification.

We also find some fault with Maccone's estimates for specific factors. Maccone uses not the rate of star formation but the number of stars in the galaxy as a factor. This ignores astrophysically-sound knowledge that the rate of star formation was higher in the early epochs of the galaxy than now, so that what must be used is the rate of star formation currently and in recent astrophysical epochs, not an implied average value over the life of the galaxy. The use of such an average thereby introduces an inaccuracy to Maccone's estimates. In addition, because the factor of the rate of star formation is moderately well-known, it begs to be represented not by a uniform distribution, which is basically a statement of ignorance of the nature of the phenomenon, but by a Gaussian. Fifth, Maccone provides absolutely no basis for his effectively using a mean value for L of 1000 years. No other investigator even attempts to estimate this completely unknown factor. Our civilization has been communicative for a little over 100 years. No one knows if it is reasonable that we will survive in this mode for another 900 years.

Numerically, Maccone chooses to sample the uniform distributions without justification to only to one-sigma limits. Using a mean and standard deviation to describe uniform distributions, in an unconstrained sampling, yields physically meaningless negative values. To avoid this, Maccone is forced to unjustifiably limit the range to one-sigma on either side of the mean.

The present study avoids these unjustified choices. We use published estimates of the various factors from six investigators. We use estimates of the current and recent-epoch rate of star formation, and use a Gaussian distribution to represent its probability density function. Because of the ignorance of values of the other non-longevity factors, we are forced to impose uniform distributions but we sample the intervals themselves rather than using their means and standard deviations and having to artificially constrain the range of sampling. We do not attempt to estimate the value of L, but leave it, as Drake himself as well as subsequent investigators did, as an unknown.

2. Analysis

2.1. Scope of the study: the joint mind

Of the factors in equation (1), the longevity, L, is basically unknown, but one can estimate the other factors based on astronomy, physics, chemistry, biology, biophysics, biochemistry, sociology, anthropology, and engineering, fields with which investigators have substantial knowledge. Table 1 provides estimates of the other six multiplicative factors in the Drake equation from six sources. The estimates make it clear that investigators disagree on their values. Here we figuratively create a joint mind, by combining all the estimates using probability arguments.

Table 1
Estimates of the various factors in the Drake Equation by different investigators [2–7], T. McDonough, personal communication, 2019].

Source	R_*	f_p	n_e	f_l	f_i	f_c	Product
Frank Drake	1	0.5	2	1	1	1	1
Cyclops	20	0.5	1	0.2	1	0.5	1
Sagan & Shklovskii	10	1	1	1	0.1	0.1	0.1
Morrison et al.	10	1	1	1	0.01	0.1	0.01
Jakosky	10	0.3	0.01	1	0.5	1	0.015
McDonough	10	0.1	1	0.1	0.01	0.1	10^{-4}

As noted, the various estimates are based on varying degrees of knowledge of many disciplines. Each investigator has a different background. The belief, however, is that, as with order of magnitude calculations, inadequacy of knowledge as well as uncertainty, motivation, bias, and other factors among the various investigators will cancel out, so that the final result represents greater discernment than that of any of the individual investigators, the figurative creation of a joint mind.

We consider the six non-longevity factors as random variables. We generate uniform distributions as probability density functions for f_p, n_e, f_l, f_i, and f_c using the ranges represented by the six estimates provided in Table 1. For the rate of star formation, R_*, both because the factor is moderately well known and because most estimates are at 10 years^{-1}, we generate for its probability density function a Gaussian distribution with a mean of 10.5 years^{-1}, the mean of the two extreme values for the rate of star formation presented in Table 1, and a standard deviation of 2.5 years^{-1}. The resulting three-sigma values are 3 years^{-1} and 18 years^{-1}. Both are 2 years^{-1} from the extreme values for the rate of star formation presented in Table 1. We generate values for f_p, n_e, f_l, f_i, and f_c randomly from their respective uniform distributions and we generate values for R_* randomly using the Box-Muller transform [8]. We then multiply the so-derived values of the six factors together to generate a product. This approach allows for uncertainty in each estimate by each investigator. Additional studies could have been used, but the ranges used for the uniform distributions most likely would not have changed significantly, if at all.

Specifically, we determine the distribution, following equation (1), of

$$m_j = R_{*,j}\, f_{p,j}\, n_{e,j} f_{l,j}\, f_{i,j}\, f_{c,j}\ , \quad j = 1 \ \ to \ \ 5000.$$

Sampling of the uniform distributions is performed by calculating

$$z_{j,m} = L_{1,m} + x_j\left(L_{2,m} - L_{1,m}\right)\ , \tag{2}$$

where $z_{j,m}$ is the result of the jth sampling of the mth factor, $L_{1,m}$ and $L_{2,m}$ are the lower and upper bounds of the interval to be sampled for the mth factor, and x_j is the value of the random variable over [0,1]. We perform this Monte Carlo analysis 5000 times, generating 5000 products of the six parameters. To ensure independence of the samplings, we perform the samplings of all the factors in one computer run. In this way, the random number generator is initiated only once, at the beginning of the run. For the rate of star formation, we find that using the mean and standard deviation noted above to define its probability density function results in none of the 5000 calculations for the rate of star formation being less than 1 years^{-1} or greater than 20 years^{-1}, consistent with the range of values for the rate of star formation presented in Table 1.

2.2. Results and discussion

Fig. 1 presents the distribution of the products generated by the 5000 Monte Carlo simulations. The mean is 0.85 $\pm$ 1.28 years^{-1}. It resembles the theoretically expected lognormal distribution. This, then, is the result of the analysis of the ruminations of the joint minds. We therefore state that, in this sense, the best estimate for the number of extant

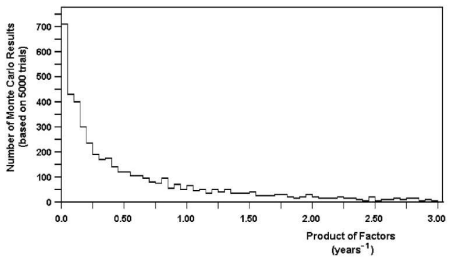

Fig. 1. The histogram of values of the Monte Carlo-determined product of the first six factors of the Drake equation. The graph displays the results of 5000 determinations of the product. The extended tail of the distribution is not shown. The abscissa bin interval is 0.05 years^{-1}. The mean is 0.85 ± 1.28 years^{-1} and the median is 0.365 years^{-1}.

communicative civilizations is given by, following equation (1),

$$N = (0.85 \pm 1.28)L \ ,$$

where L is in years. Of the investigators listed in Table 1, Frank Drake and the Cyclops report provided a value most representative of the final result, a value of unity for the product. Because of the skewed nature of the distribution in Fig. 1, we provide the value for the median, 0.365 years^{-1}.

We note that simply finding the mean of the six products, given in the eighth column of Table 1, does not provide a meaningful result in our context. That mean, 0.354 ± 0.502 years^{-1}, fails to allow for uncertainty in each estimate by each investigator, the philosophy behind our approach.

Running different numbers of simulations has little effect on the final result. The 5000 simulations resulted in 0.85 ± 1.28 years^{-1} whereas running 1000 simulations resulted in 0.87 ± 1.28 years^{-1} and running 10,000 simulations resulted in 0.86 ± 1.31 years^{-1}. In the latter case, two of the results for the rate of star formation exceeded 20 years^{-1}, and were forced to equal that value.

The present approach of multiplying Monte Carlo-selected values for parameters which are not well known generalizes the order of magnitude approach. There individual values are selected and multiplied together to provide a "best" estimate. This *multiplicative Monte Carlo analysis* can be applied to any discipline in which some *a priori* knowledge of the values of multiplicative factors exists. Using those values to determine parameters of distributions to be used as the models for probability density functions will allow this multiplicative Monte Carlo analysis technique to be employed. If more than one term of multiplicative factors is employed in a given study, the values of each factor in each term must be found by Monte Carlo determinations for each calculation of the sums of the products and the distribution of the resulting sums of the products found. That distribution, following the central limit theorem, would approximate a normal distribution. It may be that the distributions of the individual terms are of interest. The total result, however, must be generated by using Monte Carlo determinations for each factor in each term for each calculation of the sums of the products.

If the estimates of the factors result from studies of natural phenomena rather than expertise-based estimates, as in the present study, and if the means of those estimates are many standard deviations from zero, then a Gaussian distribution might be utilized as the model for the probability density function on which to apply the Monte Carlo sampling for all or most of the individual factors rather than a uniform distribution. The second requirement would ensure that values less than zero would not be generated by the Monte Carlo sampling. If these two conditions are satisfied, the Box-Muller transform could be used to randomly sample the various Gaussian distributions, as in the present study. If estimates of the factors indicate that some values fall beyond what in a Gaussian distribution would be many standard deviations, a Poisson distribution, lognormal distribution, or Pascal distribution might best be used as the model for the probability density function on which to apply the Monte Carlo sampling for one or more of the individual factors.

As the most uncertain factor, we note that the term "longevity," as it refers to L in equation (1), is often misconstrued [J. Tarter, personal communication, 2021]. The Drake equation provides an estimate of the number of extant *communicative* civilizations. That differs from the number of civilizations in the normal sense of a social and cultural artifact created and populated by sentient beings. Indeed, our civilization, existing, depending on one's definition, for hundreds or thousands of years, has only had the capability of interstellar communications over decades, since the invention of radio.

Delving into futurism, if a civilization annihilates its sentient portion, its communicative artifacts, elements of its *technosignature*, such as radio waves traveling through the interstellar medium and spacecraft with recordings and glyphs, will survive. An interstellar network of self-propagating robotic devices, such as the Bracewell probes [9] suggested by Ronald Bracewell as a means to discover and communicate with other civilizations, would certainly survive for an indefinite period, beyond the sentient portion of a civilization. Energy sources would not necessarily require the survival of sentient beings, solar cells, for example, not requiring routine human intervention. Indeed, if L_c is the longevity of a communicative civilization and L_s is that of the sentient portion of the same civilization, we can have a wide range of relative time scales, from $L_c \ll L_s$, our human situation, to $L_c \gg L_s$ [J. Tarter, personal communication, 2021].

We should note that the longevity, L_c, might alternatively be interpreted in an active rather than passive sense. Although the radio waves, spacecraft, and probes may continue to propagate or operate indefinitely, one might define L_c more conservatively as the period in which the civilization is either actively seeking to receive or actively transmitting interstellar information.

Frank Drake's famous license plate reads "N EQLS L." We hope, tongue-in-cheek, and would be greatly honored if, he chooses "N EQ 0.85L" for his next, the finding of an admiring former student.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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